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DEVELOPMENT OF METALLIZED NON-SKIDS FOR JET BLAST DEFLECTORS

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13. ABSTRACT

Tests had shown that if conventional non-skid coatings were used on the cooling modules of the Mk 7, JBD, these coatings could be destroyed when used with F-14 aircraft. In a program progressing from laboratory samples thru simulated F-14 aircraft blasts on production modules and finally to carrier sea trials, several successful systems were developed. Work on finding cheaper systems which might be considered for flight deck applications is continuing.

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DEVELOPMENT OF METALLIZED NON-SKIDS
FOR
JET BLAST DEFLECTORS

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ABSTRACT

DEVELOPMENT OF METALLIZED NON-SKIDS FOR JET BLAST DEFLECTORS

Tests aimed at studying water flow rates during F-14 aircraft launches in afterburner had revealed that conventional non-skid coatings, if used on the Mk 7 JBD cooling modules, would not hold up to the intense heat and high velocity gases. Deterioration rates were so high that no conventional non-skid material might be present at all during combat conditions. After studying the problems involved in finding a material to meet the severe conditions of a JBD non-skid coating, the possibility of developing a metallic based non-skid material was suggested. Through a series of tests, starting with laboratory samples, progressing to actual modules subjected to simulated F-14 aircraft blasts and finally to carrier sea trials, several successful systems were developed. Not only will these coatings withstand the heat of jet aircraft launches, but the possibility exists that a non-skid material which is applied once may last the entire life of the cooling module. The optimum coating will be determined after sea trial service of several coating systems have been evaluated.

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I. INTRODUCTION

A. BACKGROUND

It was determined during testing of water flow through the proposed cooling modules (617156-1) of the MK 7 Mod 0 JBD (Jet Blast Deflector) that the conventional deck coverings used for non-skid coatings (per MIL-D-23003) would not withstand the heat of the jet blast of the F-14 aircraft in afterburner. Indeed, the combination of high heat and erosive effect of high velocity gas flow could completely remove the standard organic base non-skid compounds with one or two launchings.

The problem had been uncovered when NAVSHIPS (Naval Ships Systems Command) was engaged in a joint investigation involving the NAVSEC (Naval Ship Engineering Center) and NAEC (Naval Air Engineering Center) to develop a module coating which would act both as a thermal insulator to reduce water flow requirements, as well as a non-skid coating. This program was the result of NAEC studies conducted at NATF (Naval Air Test Facility) which had shown that cooling module water flow requirements would mean an additional fire main pump dedicated to each JBD unless flow rates could be reduced.

A multitude of coating systems which included epoxies, ceramics, polymers, cermets, metal laminates, silicone resins, and silicone rubbers were tested on full scale simultion of a MK 7 JBD installed at NATF, as well as scale model simulation tests conducted by NAVSEC at the Puget Sound Naval Shipyard. It was found in these tests that none of the coatings have sufficient thermal insulation quality combined with adequate practicable service life to act as a suitable insulator. A fallout of the studies was the realization that none of the materials investigated (including the standard flight deck non-skid coatings meeting specification MIL-D-23003) would be expected to give adequate service life as a non-skid coating, particularly with F-14 aircraft in afterburner.

The possibility of using metallic coatings (because of their inherently high softening temperature combined with sufficient ductility to withstand thermal shock) was proposed at NAVAIRENGCEN. The problem was finding a metallic coating which could be applied in such a way as to provide a non-skid surface, withstand the effects of F-14A aircraft jet blasts and hold up to the combined corrosive environment of a marine atmosphere plus the heat and gaseous elements of a jet aircraft blast. The plan was to first, as quickly as possible, find a usable coating to meet the immediate requirements. A test procedure which would allow rapid, inexpensive screening of candidate coatings was also sought, lest the cost of finding a suitable coating become too prohibitive. Once a usable coating was found it was hoped that test procedures could be developed which would permit ultimately finding the most outstanding metallic non-skid system.

B. SCOPE

This report is divided into two parts. In part I, the development of a successful coating system is discussed. In part II, the efforts in finding a possibly more cost effective coating is detailed.

This report provides a description of the developmental efforts conducted in the pursuit of an adequate metallized non-skid coating for JBD applications. These efforts included salt spray, wear and friction tests as well as conventional jet blast tests. Metallurgical and application problems are also discussed.

The discussion is arranged chronologically. However, some concessions are made in the time scale because of the overlapping aspects of the several branches of the development. Tabular data are presented in support of several points in the discussion. Photographic representations are included in an appendix. The table of reference is a partial bibliography of the test reports previously issued regarding fragments of this investigation.

II. SUMMARY

A test program for proving the feasibility of metallic coatings was developed. The test regimen included bench tests for thermal cycling susceptablity, friction testing, corrosion response. From here, successful candidate coatings were applied to actual production cooling modules and subjected to simulated F-14 aircraft jet blasts in afterburner at NATF. The test at NATF included some accelerated corrosion to allow an examination of the interaction between corrosion and aircraft jet blast effects.

Materials capable of passing the test regimen were used on shipboard modules where they saw actual service tests.

One coating, flame sprayed nickel-aluminide, was applied to the surface of a module and installed on the CVA-59 where it was exposed to more than 4200 launches, at least 1119 in afterburner. The module coating was still usable after this service, suffering only from some pitting corrosion.

Based on the success of this module, all the modules at the #1 JBD of the CVA-63 were coated with nickel-aluminide (plus a sandwich layer of zinc for improved corrosion). These modules have performed very successfully for 10 months.

At this point they have shown no signs of damage, not even the corrosion pitting observed on the module coated with nickel-aluminide without zinc.

All production modules are now being coated with a heavily textured nickel-aluminide developed for increased wear resistance. Corrosion protection is obtained by coating with an aluminum silicone high temperature paint.

Work on alternate systems is continuing in an effort to find the optimum cost effective coating system. To date, modules coated with aluminum spheres covered with arc-sprayed aluminum have survived one year of service on the CVA-62, although some of the modules have exhibited delamination. A single test module of heavily textured arc-sprayed aluminum has survived six months of service in a test on the CVA-59. During this time it has seen 1239 launches, of which 770 were in afterburner.

One test module coated with arc-sprayed aluminum-molybdenum which exhibited some small areas of blistering after two months of sea trials was removed from the CVA-59.

III. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. It was possible to develop application techniques which gave the metallic coatings adequately high friction coefficients so as to warrant their consideration as JBD non-skids.

2. All the metallic coatings, when tested, displayed the ability to withstand the heat of the direct jet blast of F-14 aircraft without suffering any deterioration or erosion.

3. Corrosion of the module underneath the coating and delamination of the coating was the most serious problem encountered. Wear resistance might limit the usefulness of some coatings for extended service.

4. Based on the sea-service tests performed to date, it appears that several metallic non-skid systems have been developed which will give adequate service. These coatings have proven significantly superior to conventional flight deck non-skids when exposed to F-4, RA-5 aircraft jet blasts. Based on tests at the NATF, they are expected to hold up to F-14 aircraft jet blasts.

5. It appears that coatings capable of giving service for an entire R.A.V. period are probable, and that a coating which lasts for the entire four year period between overhauls is possible.

B. RECOMMENDATIONS

1. Continue to coat JBD Cooling Modules with metallic non-skids.

2. Run a sea trial test with a production quantity of modules coated with textured arc-sprayed aluminum.

3. Until sea trial tests have been evaluated, coat all other modules with flame sprayed nickel aluminide plus some protective layer.

4. Continue bench test development so that variations can be tested and used to make improvements. Test the more promising coatings at the JBD Test Site at Lakehurst.

5. Since some of these coatings have performed so well in tests to date, conduct tests in other critical deck areas to determine if some of the metallic systems developed for the special JBD applications might be advantageously used to replace conventional non-skids. These areas might include V/STOL take off pads, heavy cable wear areas, and Harrier Landing pads.

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VII. DISCUSSION

PART I - DEVELOPMENT OF THE METALLIZED NON-SKID COATING

1. Assessment of Problem. The initial investigations of possible insulating materials on cooling modules had shown that almost any organic material used for a non-skid coating has little chance of surviving the heat of the F-14 aircraft Jet Blast in afterburner for any length of time (see Reference 1). This meant that any of the conventional non-skids would be expected to deteriorate or erode rapidly, thus requiring many re-applications. In simulated F-14 afterburner blasts, conventional epoxy based non-skids were completely eliminated in one launch. The possibility of using a metal-sprayed coating was suggested as a method obtaining a non-skid which could survive the intense heat of the jet blast.

The coating was to have the following characteristics:

1. Coefficient of friction greater than one under dry, wet and oily conditions.
2. Ability to retain characteristics when hit by a F-14 jet blast.
3. Ability to be easily repaired.
4. Ability to exist without serious deterioration in the marine environment of an aircraft carrier.
5. Ability to maintain friction coefficient after periods of wear caused by use.

INITIAL COATING SELECTION

Since metallic coatings have high melting (and softening) temperatures, they could be expected to take the high temperature effects of the jet blast. Their inherent ductility meant they would withstand thermal shock better than ceramic or cermet coatings. The problem was to find a metallic coating system which could be applied in such a way as to have high coefficient of friction, adequate corrosion response, and adherence to the aluminum module under thermal strain cycling.

Such a metal should be hard (for good wear resistance), have adequate corrosion resistance to marine atmosphere and give good adherence to the aluminum cooling module.

For both economic reasons, and because a fusing process would destroy the properties of the cooling module, it was felt that the coating should be applied as a direct sprayed coating (as opposed to a spray and then fused coating that is used for some hardfacing operations).

It was felt that the possibility of repair would be enhanced by the use of wire spray techniques. For this, and potential cost considerations, a wire spray, as opposed to plasma or flame spray technique was initially examined.

A coating of nickel-aluminide, (METCO 405) was the initial recommendation made by the metal spray supplier. This material is a relatively hard, good wearing material; it in itself has adequate corrosion response to a marine atmosphere and it reportedly has the best adherence of any metallized coating.

Both the adherence and wear resistance of this material is the result of a unique alloy system. In wire form, the nickel and aluminum are not alloyed. As heat is applied to melt the wire for spraying, the aluminum and nickel combine to form a series of very hard intermetallic compounds in a reaction which is highly exothermic. The exothermic reaction supplies localized heat to the material just as it is hitting the substrate being sprayed. This heat allows a metallurgical fusion to take place, thus leading to the excellent bond. The bond formed is reportedly more adherent than that of any other metal sprayed coating, regardless of the spray technique.

THERMAL CYCLING TESTS: The first task in the program was to determine whether or not the coating would stand up to the heat and whether the adherence of the coating would withstand the thermal strain cycling resulting from the temperature gradient across the module (coupled with the different expansion coefficients of the coating and module materials). A preliminary test was run as follows: A coupon of aluminum alloy 6061-T6 was sprayed with a coating of nickel-aluminide (0.015" thick). A thermocouple was inserted thru the uncoated side so that the bead was flush with the surface of the coated sample. An oxy-acetylene torch was used to provide the heat source. The sample was heated with the oxy-acetylene torch so that the surface rose to 600° F in fifteen seconds, held at temperature for 30 seconds, then cooled back to room temperature by spraying the back of the coupon with cold water. The cycle was repeated 50 times. (Test setup is shown in Figure I). The coupon, when examined, showed no visual signs of deterioration. Metallographic examination revealed the presence of a good metallurgical bond; there were no indications, even on a micro scale, of any bondline tears, cracks; nor was there indications of any excessive metal diffusion, either of module into the coating or coating down into the module.

FRICTION COEFFICENT: With preliminary indications that the coating might hold up to expected heat and thermal shock, samples were then prepared to determine the ability of applying a coating which would have the necessary friction coefficient. It was found that by reducing the air pressure used to blow the molten wire material of a spray, spattered irregular coating texture was developed. The coating develops a peak/valley ratio of 0.010". The roughened coats were applied over a bond coat of non-textured METCO 405. Work was done at METCO, and samples having what appeared to be an adequately rough surface were tested for friction coefficient. The static friction tests were made using an Olsen Slipmeter.

Using a 12" x 12" sample, measurements were taken in two 90° directions, one diagonal direction. Measurements were taken on a dry surface, a surface wet with a layer of water, and a surface coated with JP-5 fuel. The results are shown in Table I. Under all conditions, the coating samples met the requirements originally established.

It was learned at this time that concurrent with the preliminary testing of metallized non-skids at NAVAIRENGCEN, a program at the Bremerton Naval Shipyard sponsored by NAVSEC had also reached the conclusion that a metallized coating offered the best chance of survival. (See Ref. 2). In the Bremerton Tests, neither coating costs, surface roughness nor possible field applications had been considered. The coating offered as the best of those tested was a two-layer plasma sprayed coating. The first layer was a plasma nickel-chrome-aluminide (METCO 451), the chrome being added to give the NiAl enough high temperature stability to allow plasma spraying. The top layer was a mixture of METCO 451 and ZrO_2. A coupon sample was obtained of the plasma sprayed coating. It was observed at this time that the surface texture of the plasma coating was obviously smoother than that developed for the flame sprayed coating (peak to valley ratio of 0.005"); in spite of this, the static friction coefficients were about the same as those first measured in Table I for the flame sprayed coating. The question of what the friction coefficients would be like after some service wear or dirt build up was questioned. It was resolved that should coating systems be found which had 1-4 years service life expectations, friction coefficient after-wear would also require study.

JET BLAST TESTS: To complete the initial goal of obtaining a usable coating, an actual module sample was required. A Mark 7 JBD panel was obtained; one-half of the module was coated with the organic coating which had given the best test results to date (Ref. 1). The other half was flame sprayed with 0.010-0.015" of textured nickel-aluminide (METCO 405). The panel was installed in the test site at Lakehurst, and exposed to 20 simulated F-14 jet blasts in after-burner (using the F-111). At the end of the tests, the organic coating (Palmer 113) had started to erode. The metallized coating was completely intact. Visual surface examination revealed no damage.

For the NAVSEC plasma coating a sample JBD module was coated at A & A Manufacturing of Clifton, N.J. and the module was tested at Lakehurst with 20 simulated F-14 jet blasts. The coating also showed no damage. Plans were made to coat one module each with the flame sprayed coating and with the plasma variation and have each installed in the center row of the Mk 14 JBD being installed on the CVA-59.

While only a limited number of tests were planned for F-14 Aircraft launches, it was felt that a valid evaluation of the coating life would still be obtained from its service life on the carrier.

CORROSION TESTS

1. Salt-Spray - Prior to the sea trials on the CVA-59, other tests had been started at NAVAIRENGCEN. After the coating of METCO 405 had shown the ability to act as a non-skid slip system after withstanding the heat of an F-14 aircraft blast, an examination of other potential problems had been started. Earlier work on the use of metallized coatings on maraging steel had shown that the protective corrosion qualities of metallized coatings were somewhat compromised by their inherent porosity. (See Reference 4). To test this, flame spray coated coupons of metallized 6061 were exposed to 5% NaCl salt spray for 168 hours. (The test time was arbitrarily picked; the 168 hours exposure, when used with zinc or cadmium, will corrode to about the same degree as a panel exposed to a marine atmosphere would corrode in 18 months.) The coupons developed many small corrosion pits (Figure 2). The pits, when examined metallographically, were seen to be the exfoliation of the aluminum module surface. Corrosion was taking place because of penetration through the coating porosity. The corrosion oxide was more voluminous than the original aluminum, and the oxide was "growing" up through the pore. A sample coupon of the plasma sprayed coating was also exposed to the 168 hour salt spray test. While this coating did not exhibit nearly the amount of general pitting, some blistering was observed. (Figure 3). Some concern arose as to how these corrosion defects would interact with the effects of a jet aircraft blast. To study this, a final screening test was needed which could be used in the subsequent developments.

2. Accelerated Corrosion - Aircraft Jet Blast Interaction - To study the effects that corrosion might have on jet blast performance, a test which would rapidly induce corrosion while exposing materials to the jet aircraft blast was designed. Coated modules, as before, were exposed to simulated F-14 jet aircraft blasts using an F-111 Jet Aircraft. Now, however, after each aircraft blast was complete, the module was hosed down with a sea water-salt mixture. In addition, after the day's tests were completed, a blanket saturated with sea water was layed across the module.

Both test modules used for the jet blast study were tested. After the first additional 15 jet blasts, a layer of the flame sprayed material delaminated (Figure 4). It was observed that damage was limited, and 20 additional exposures caused very little further damage (Figure 5). Additional exposures carried the test out to 50 corrosion jet blast exposures, and damage apparently stopped. This was not the case with the plasma coated sample. Heavy blistering continued to extend into the coating, and large areas delaminated.

(Figure 6). The delamination was severe enough that it was predicted that the plasma coating would not be suitable for sea service. As tests were already planned for the CVA-59, and since the corrosion tests were only an attempt to simulate actual sea exposure, it was decided to allow the CVA-59 test exposures to go as scheduled.

It was hoped that these tests would give some correlation with the results of the Lakehurst tests.

Results of the module coatings after periods of sea trials are shown in Table II. The plasma coating, after less than three months service, had failed almost exactly as had the test module at the NATF tests. (Figure 7). A 15% loss in coating developed, and an underlaying network of porosity also developed.

Dirt films had also caused a drop in friction coefficient. The wire sprayed coating while developing some pits, was still performing satisfactorily. It continued to see service until it had been used for 13 months.

During this time, the module had been exposed to 4200 launches in the first 10 months of which 1119 had been CRT launches. (Totals for the 13 month period are not available.)

Examination of the module showed some corrosion pits had developed, but the coating was still intact. Note the difference between the metallized coating vs. the gouged appearance of the surrounding epoxy non-skid coated modules in Figure 8. A layer of carbonaceous material had grown on the surface, and some wear had occurred. Friction measurements had a friction coefficient of 0.8 dry, 0.7 - 0.75 under oily conditions. In all, the module had survived the service, and appeared to be still usable with no refurbishing, although a system with better corrosion resistance and possibly a rougher surface profile might represent an improvement. The sequence of tests led to the following preliminary conclusions.

1. Some metallized coatings could withstand the thermal spray environment of jet aircraft blasts.
2. Corrosion interactions could have some serious effects on successful performance.
3. Salt spray tests gave some correlation with expected shipboard performance (blistering of the plasma coating developed by NAVSEC) in these tests was found in the NATF tests, and again in the sea trial on the CVA-59.
4. Correlation with the NATF accelerated corrosion jet blast - interaction test accurately predicted the failure of the plasma coating in actual sea trials.
5. A wire sprayed coating of nickel aluminide (METCO 405) gave adequate service life as a JBD module coating.

Based on these results, a screening test program for future developments was established. These were as follows:

(1) Friction Coefficient Tests
(2) Salt spray corrosion tests
(3) Jet blast exposure
(4) Accelerated corrosion - jet blast exposure tests.
(5) Sea Trials of selected coated modules.

IMPROVED VARIATIONS IN NICKEL ALUMINIDE COATINGS

A. Flame Spray Variations

Since the METCO 405 coating which was performing adequately on the CVA-59 was not completely unharmed by the combination of corrosion, jet blast environment in the NATF tests, development of an improved coating was sought. Examination of the corrosion coupons had revealed that the problems were caused by the exfoliation of the 6061 aluminum alloy of the module. The high degree of porosity of the flame coating allowed this corrosion product to escape to the surface. The relatively dense plasma coating, while having enough porosity to allow moisture to reach the surface and start corrosion, was too dense to permit the voluminous oxide to extend out to the surface. Thus, the oxide would further stress the bond line until it forced delamination. These were the blisters observed in the salt spray tests. The aerodynamic effect of the jet blast was to further stress the blistered metal until the coating was actually pulled off.

Modifications were tried to reduce the exfoliation of the coatings. The sample combinations tried in a test program are listed below:

1. METCO 405 (NiAl) coated with sprayed aluminum
2. METCO 405 coated with an aluminum rich silicone paint
3. A bottom layer of sprayed aluminum, coated with top layer of NiAl.
4. A sandwich of NiAl, aluminum sprayed NiAl.
5. Layer of sprayed zinc covered with NiAl.
6. A sandwich of NiAl-Zinc-NiAl.

The test samples were sprayed by METCO at their Westbury labs.

The results were as follows:

Both the top coatings were successful at stopping the pitting corrosion (Figures 9 and 10); however, the surfaces were now covered with an almost slippery oxide product coating. It was felt that such a surface would no longer be a useful non-skid system. Coatings 3 and 4 were disappointing. Neither caused any decrease in the amount of surface pitting. The best results were obtained from coatings 5 and 6 (Figures 11 and 12). There was a slight amount of what might be incipient blistering in coating #5. The zinc oxide corrosion product, being less voluminous than that of the aluminum, allowed corrosion to occur without the damaging bondline stresses and delamination.

A production module was coated with the (NiAl-Zn-NiAl) system. The test module was given the same test sequence as had been used for the other metallized coating (20 simulated jet blast hits, followed by 50 jet blasts, followed by salt water spraying at NATF). The coating was undamaged by the tests; this was the first coating to go through the test regime with no delamination of any type (Figure 13). Since the Lakehurst tests had now shown some correlation with sea service, and since the Zn sandwich had performed better than the pure METCO 405, the NiAl-Zn-AlAl coating was adapted as the most reliable of the JBD coating systems. (See Fig. 3).

The modules for the #1 JBD of the CVA-63 were coated with this system. As of March 1974, the modules had been in use for 11 months of sea service and had performed with no damage of any kind noted. Even the corrosion pitting which had been noted on the straight nickel-aluminide was not in evidence after 7 months sea service using the MPR-1056 system, (see figure 14). The success of this system led to coating all of the modules on the CVA-65 with this system. These modules had been in use for the first F-14 aircraft use and as of 6/74, panels exposed to 4500 combined Landings/Bolters and the coating still looks good.

The one possibly deficient area of the MPR-1056 system is the relatively low surface profile. Such a profile might limit service life because of wear and or filling up with dirt. In coating the modules at Hunters Point for the CVA-63, a method of increasing the profile roughness was found. It involved modifying the air cap used for spraying. With this modification, a peak/valley profile of 0.020" could be developed. This rougher coating seemed to allow heavier corrosion of the zinc underlayer using the sandwich system; however, it was remembered that the use of a sprayed aluminum or aluminum-silicone paint sealer had given the best corrosion response in the salt spray test. The problem then had been the observation that the friction coefficient had been degraded as a result of corrosion. It was felt that with the roughened surface developed with the new technique, this would no longer be a problem.

Samples of the heavily textured coat were prepared and tested. The salt spray results were excellent. As a further test, the surface coating was heated with a propane torch (per figure 1) 50 simulated cycles, then exposed to salt spray testing. This was done to insure that no interaction between the jet blast and the silicone sealer would affect the corrosion results adversely. In the course of testing, the aluminum temperature was accidently allowed to climb to the point where melting occurred; yet the metallized coating and the sealer remained in operable condition.

The coupon was placed into salt spray testing after the thermal cycling test, and no adverse pitting corrosion took place. All that was observed was the corrosion of the sealer film (see figure 15) but now because of the roughened profile the friction coefficient did not suffer.

For greatest integrity, the coating is applied in three layers. The base coating is the conventional nickel-alumunide for maximum adherence. The profiled layer is added next, built up to a total thickness of 0.015". The sealer coat is then added for corrosion protection. It is hoped that this heavily profiled metal will extend the useful life of the coating to the predicted four year life of the modules. This system was used to coat all the modules of the CVA-67 and CVA-68.

II. DEVELOPING THE OPTIMUM COST-EFFECTIVE COATING

Once it was established that a system had been developed which would provide a safe, reliable non-skid system for the JBD modules, it now became possible to think of developing the most cost effective system. To a large degree this might not be possible to completely answer until more details about the life of the module itself are determined. For example, a slightly more costly coating which has a useful life of four years, versus only one for the cheaper system is not warranted if the module itself will only be useful for one year.

The flame sprayed metallized coating had been found to be both cheaper and more reliable than the plasma coatings. Some variations in flame sprayed were examined, including one test of a nickel aluminide powder which was pre-alloyed prior to spraying. This coating blistered badly in the standard salt spray corrosion tests (see Figure 16.) When considering how much of the cost of coating modules was tied up in the application labor, thoughts were given to the fastest application technique. Through consultation with some of the major suppliers of metallized coating, it was learned that the fastest metal spray system capable of the greatest deposition rates was the electric arc spray. The arc spray coatings, for a given metal, were also capable of achieving the best adherence for a given material to be sprayed.

Other factors to be considered are the effect of surface texture. As will be discussed later, surface profiles much rougher than those obtained with flame sprayed nickel aluminide can be obtained. The rough profile in itself will add to wear resistance, since it offsets the effect of clogging the surface profile by a dirt (and/or rubber, jet char) film. How serious this requirement is will not be known until some of the flame sprayed coatings have seen 2-4 years of service.

Finally, although a definite correlation between blistering in the salt spray test and delamination in service was observed, no definite correlation for other types of corrosion exists. Pitting was observed in flame sprayed nickel-aluminide and again in service, but it would not prevent a module with this coating from giving acceptable service in a 13 month sea trial. How well coatings which develop various degrees of pitting, (especially aluminum containing mixes which develop surface pitting) will hold up in sea service is still unknown.

ELECTRIC ARC SPRAY COATINGS

At this time it is not possible to spray nickel-aluminide with the electric arc spray, although a possible technique is discussed later. Two alternate coatings were suggested by metal sprayers as substitutes. They were:

1. Aluminum Bronze -Wall Colmonoy Corp.
2. Aluminum Aggregate trapped by aluminum overspray - Avtec Corp.

A sample JBD module of each was supplied for Lakehurst tests. Samples of both were screened through 168 hour salt spray tests, followed by Lakehurst simulated F-14 jet blast-corrosion tests.

The aluminum bronze coating was applied in a total spray time of 10 minutes, compared to the two hours required for MPR 1056. The coating showed some indications of metallurgical bonding when examined in a metallographic section. When corrosion tested in the 168 salt spray, the coating developed blisters similar to those obtained with the plasma sprayed coatings (Figure 17). The subsequent behavior at Lakehurst was also similar (Figure 18). Bond lin corrosion resulted in blistering and delamination. This again demonstrated the ability of the salt spray test to act as a screening test. It also showed that coatings which themselves are very noble to salt water corrosion could easily cause heavy galvanic corrosion of the module surface.

ALUMINUM AGGREGATE TRAPPED BY ALUMINUM ARC-SPRAY (AVTEC)

The avtec coating was unique. The coating had been developed for SATS matting in a Government sponsored program in 1967. At that time, the field test results had been disappointing, and as costs for applying this coating were more expensive than applying standard non-skid, the program was dropped. For JBD applications, however, the cost of the arc-sprayed coating was considerably lower than that of the wire sprayed nickel-aluminide.

The coating relied on using aluminum spheres as aggregate. The spheres had been developed as the aggregate for standard non-skid to be used in deck areas where heavy cable drag occurs. The aluminum aggregate is used to minimize damage to cable that runs across the coating. The aluminum spheres are somewhat of a compromise in that they do not wear as well as standard ceramic type aggregate, but impart non-skid performance without damaging cable.

The coating is applied in two steps. The aggregate is "bonded" to the surface by a preliminary arc-spray technique. (The technique used was proprietary.) The module was then electric arc oversprayed with a heavy aluminum coating. Since the coating is all pure aluminum, no corrosion damage was expected (sprayed aluminum is being used in many Naval applications as a corrosion preventative coating), and none developed. The coated module performed well for the Lakehurst simulated jet-blast-corrosion tests. (Figure 19). The posaiblity of flexing causing the aggregate to come loose was also tested by flexing the module 2000 times at a strain of 1/4"/foot (Maximum bow allowed in the module) and again no damage occurred.

The primary reason for caution with the METCO 405 wire sprayed systems was the corrosion interactions. The corrosion was not a factor with the trapped aluminum-aggregate oversprayed aluminum system, and the Lakehurst tests combined with the NAVAIRENGCEN flexure tests had indicated that adherence under jet blast and flexure were good. Because of the cost savings involved (based on outside contractor quotes, the nickel-aluminide system (MPR 1056) would run $12/square foot, as opposed to $3-5/square foot for the Avtec System) it was felt that the Avtec systems was deserving of a large production lot trial and accordingly, it was decided to test an entire JBD panel on the CVA-62. The 42 modules were installed in April 1973.

Results of the sea trial tests are summarized in Table IV. The reliability of this system does not appear to be as good as the NiAl based systems. Reports of aggregate coming loose in the initial operations indicate some personnel nuisance (if not danger). Two modules exhibited some delamination after two months service. After a year of operation (4000 launches, 487 in afterburner) about 30% of the modules show some delamination, although the modules are still considered usable and ships forces report frictional quality is still acceptable. The delamination which did occur marked the first time that material which survived the testing at NATF exhibited some degree of deterioration in sea service.

OTHER ARC SPRAYED METHODS

The trapped aggregate coating had been applied by a small manufacturing company using a propritary application technique. Toinsure the capability of the Navy to apply the arc-sprayed aluminum coating, Wall Colmonoy Co. and METCO were both asked to demonstrate that their metallizing equipment could duplicate this coating. Both companies had difficulty initially in trapping the aluminum aggregate, and both came up with alternate suggestions (both companies, with the help of NAEC personnel were eventually able to duplicate the Avtec coating). Wall Colmonoy demonstrated that by reducing the air pressure used for spraying, a highly textured coating could be obtained by using a reduced air pressure for spraying. Coatings with peak-to -valley ratios of 0.060" were possible. Such a coating would provide all of the friction offered by the aluminum aggregate, but could be applied in a single step. The cost of such a coating might possibly be applied for as little as $1.00/square foot. METCO had found that by using a wire of molybdenum along with a wire of aluminum, a combination coating develeped which was highly textured, and had a hard wear-resistant aluminum-molydenum component which offered wear resistant characteristics.

OTHER METALS

A preliminary investigation program was conducted by the Wall Colmonoy Co. Three different alloying wires were considered as a combination were to be used with aluminum. These were:

1. Zinc - Selected because its' inexpensive, offers additional corrosion resistance and might improve wear life of the pure aluminum.

2. Nickel - Picked because it is cheaper than molybdenum, might form some nickel aluminide during spraying to improve adherence.

3. Molybdenum - Selected because sprayed molybdenum is second only to nickel-aluminide in adherence, can improve wear resistance of aluminum, and because preliminary tests showed that it had good corrosion resistance. In addition to composition variations, the aluminum was sprayed to different surface textures.

By using wires of two different sizes, it was possible to obtain variations in compositions. Sample coupons were prepared over three different surface preparations. These were:

1. Silicon carbide grit blast (-40 mesh)
2. Disc - grind abrade
3. Steel grit blast

A crude evaluation of bond strength was achieved by breaking a corner in a vise and observing the fractures. Coupons were also subjected to 168 hour salt spray tests. Results are compiled in Table V. Corrosion coupons are shown in Figures 20.

It appeared that nickel- or molybdenum additions improved adherence. The aluminum-molybdenum and the aluminum-zinc system had the best corrosion resistance, although the aluminum-nickel systems were comparable to pure nickel-aluminide, suffering only from occasional surface pits. To get some feel for wear resistance, sample coupons were subjected to the wire cable tests per MIL-S-24443. However, the main concern was to test the wear effect of the cable rubbing on friction coefficient. Results are shown in Table V.

Several significant obervations worthy of note can be made of the test results.

1. For the coatings studied, nickel-aluminide had the best coefficient of friction, regardless of the roughness of the surface profile.
2. Even with heavily profiled surfaces, aluminum arc sprayed coatings had barely marginal friction coefficients after wear testing.
3. Additions of nickel and molybdenum improved the wear resistance of the profiled aluminum.
4. When tested, none of the coatings were detrimental to cable wear. Since no correlation between wear in this test and actual wear of a flight deck material exists, it is difficult to predict just how long a textured aluminum module can give service in actual practice. The low value is only pertinent for a completely oily surface which will exist only in very limited circumstances. Thus, the actual acceptability of the aluminum coating can only be established by actual sea tests.

Also to be established is whether or not pure aluminum coatings, without the effect of aluminum aggregate, will hold up without delaminating. As no adherence tests have been developed which can predict this accurately, (even the Lakehurst jet blast tests have not always been capable of predicting delamination) this also requires actual field testing. If adherence does become a limiting factor, the use of a bond coat of nickel-aluminide might be used (as it is for some corrosion coatings).

If wear does become a limiting factor, the addition of a second metal can be used. A mixture of 50% (by volume) nickel and aluminum actually corresponds quite closely to nickel-aluminide. Metallographic examination shows that such coating, when electric arc sprayed, resembles nickel-aluminide with some amount of unreacted aluminum. Such a coating might be expected to have superior wear and adherence to pure aluminum, but inferior to pure aluminum or aluminum-molybdenum for corrosion. As seen in Figure 20, the excess aluminum becomes the anode of a galvanic cell, and heavy localized corrosion pits occur. This corrosion behavior also requires sea service examination. Pure nickel-aluminide did survive 13 months service even though it showed pitting in bench type tests. If a high texture can be developed in applying nickel-aluminum by an arc spray (here it should be noted that the greater the texturing, the less complete will be the nickel-aluminum reaction) then a protective coating can be applied.

If nickel and aluminum could be successfully applied using the electric arc spray, it would reduce costs of applying a metalized coating to JBDs in half.

For evaluation, two coatings representing extremes were selected for testing. One was pure aluminum, representing the cheapest to apply and most corrosion resistant of the coatings. The other was Mo-AL (50% by volume) representing the best combination of wear and corrosion resistance of the aluminum-plus-other metal systems. Test modules were coated with both systems; the pure aluminum coating by the Wall Colmonoy Co. in Detroit, Michigan, and the Mo-AL coating by A & A Co. in South Plains, N.J. Both modules successfully passed simulated Jet Aircraft Blast plus accelerated corrosion at NATF.

The same modules were then installed into the #1 JBD on the CVA-59. As of March 1974, the modules had seen two months of sea service.

The Aluminum-Molybdenum coated module had shown some signs of delamination. The module was removed from the ship, in fear that continued delamination could lead to pieces of coating coming off and causing personnel or equipment damage. Metal loss was restricted to small areas and had the appearance of spalling.

The adherence failure of the Al-Mo coating was somewhat unexpected. Possibly it shows that a coating with high cohesive strength and marginal adherence will suffer more than a weaker material (like pure aluminum) having the same adherence. The relatively poor adherence of high performance non-skid versus regular non-skid is similar in that the tougher high performance material will lose adherence to the deck far more easily than conventional, (weaker) non-skid materials.

The fact that the module apparently failed in service after passing tests at NATF was also significant. The Al-Mo coating was the second such coating to behave this way (the Avtec coating also exhibited peeling on some modules on the CVA-62 after passing tests at NATF). Since the NATF tests were successful at predicting the life of coating systems which suffered primarily from corrosion defects, it is possible that the effects of mechanical stresses on coatings with marginal adherence is the weak spots which the NATF tests ignore. This, conceivably could be tested at the new operational JBD test site built at Lakehurst.

As of June 74, the pure aluminum module had been exposed to 1200 launches, of which 770 had been in afterburner. (See Table IV). The module had suffered no delamination and reportedly had lost very little or none of its non-skid ability. In contrast, modules coated with the trapped aggregate system on the CVA-62 had shown some delamination at this point in their sea trial test. Thus, as predicted, the textured aluminum is outperforming the two part trapped aggregate system If the pure aluminum system continues to perform well, it is possible that such a system might even be competitive with epoxy non-skids for standard flight-deck applications.

CONCLUSIONS

Metallic non-skid systems based on the use of flame sprayed nickel aluminide have been developed which are capable of performing on JBD modules. These coatings can survive the effects of jet-blasts, marine environment, wear, and still be serviceable for periods of 13 months. Improved coatings show promise of performing even longer, hopefully for periods of 4 years, the expected life of the modules.

Other systems have been developed which could be applied at significantly lower costs which also show some promise of giving long useful life.

VIII. REFERENCES

1. NAEC-ENG Report No. 7707, Investigations in Support of Mk 7 Jet Blast Deflector Cooling Module Design.

2. Puget Sound Naval Shipyard Report No. E-3864-74, Determination of Temperature Protection Capability of Select Coatings.

3. NAEC TPR NO. 73-73, Mk-7, Cooling Module Tests

4. Budd Co. Technical Report, Catapult Tow Media, Metal Plasma Sprayed Maraging Steel Specimens, Nov. 1971.

TABLE I

Coefficient of Friction of Metalized NiAl.

Coating Profile - Peak to Valley - Ratio - 0.008"

	DRY	WET	OILY
Coefficient of Friction	1.06	1.03	1.02
	1.04	1.04	1.01
	1.06	1.06	1.02

TABLE II

Comparison of Module Coatings After Sea Service on the CVA-59

A. Launch Exposures

	F-4 CRT	F-4 MRT	RA5 CRT	A3	A7	A6	C2	CUMULATIVE TOTAL	CUMULATIVE CRT
Plasma Sprayed NiCrAl-ZrO_2	220	326	102	80	33	51	126	* 938	322
Flame Sprayed METCO 405	812	1428	307	376	467	423	420	4196	1119

* Pulled Off After Two Months Service

B. Final Coefficient of Friction

	DRY	OILY
Plasma Sprayed NiCrAl-ZrO_2	.75	.63
Flame Sprayed METCO 405	.8	.72 - .81

C. Appearance

Plasma Sprayed NiCrAl - Delaminated, Network of Blisters (See Figure
Flame Sprayed METCO 405

15% loss consisting of small pockets of spalled material where corrosion blisters had formed. No delamination, film still intact.

TABLE III

Results of modules coated with flame sprayed zinc sandwiched between layers of flame sprayed Nickel Aluminide (MPR 1056) after sea service on the CVA-63.

LAUNCH EXPOSURE

TOTAL TO Dec 73	F-4 MRT	F-4 CRT	RA-5C CRT	A-6	A-7	C-1/C2	S-2	E-2	CUMULATIVE TOTAL	CUMULATIVE CRT
	122	33	28	241	305	16	265	101	1111	61
TOTAL TO Mar 74										
	175-	85	47	358	488	43	593	173	1996	132

Examined January 1974 - No damage of any type noted, no corrosion observed.

Friction coefficient (Deck Measurements)

Dry - .80

Wet - .75 - .80

Friction Change (Crew Report) None

Damage - None

TABLE IV

Results of Arc Sprayed Coatings after Sea Trials as of June 1974.

Coating/Ship	AIRCRAFT F-4 MRT	F-4 CRT	RA-5C MRT	RA-5C CRT	LAUNCH EXPOSURE A-3	A-4	A-6	A-7	C1/C2	S2	E2	TOTAL	CRT	% CRT
CVA-62 AVTEC Coating (Installed 4/73)	476	321	48	166	81	3	982	1261	160	281	221	4000	487	12%
CVA-59 Textured Aluminum (Installed 12/73)	0	616	0	154	21	132	233	91	12	-	-	1259	770	61%
CVA-59 Al-Mo Installed 12/73 Pulled 2/74	176	2	0	45	46	0	145	286	87	-	67	854	47	5.5%

APPEARANCE-

AVTEC Coating - 15 of 45 Modules show 5-20% Delamination
Al-Mo - Module showed 3-5% spalling
Textured Aluminum - No Change Reported

FRICTION COEFFICIENT

AVTEC Coating (As of 6/73, 3 month service) Dry - 0.8 - 1.0 Wet - 0.7
Ship Reports Satisfactory
Al-Mo (As of 2/74 Dry - 0.5- .0.9 Oily - .80 - 1.00

Textured Aluminum - Ship Reports - Friction Quality, Excellent

TABLE V

Effects of Addition of a Second Metal to Aluminum Sprayed Coating

METAL	PER CENT BY VOLUME	BEND TEST ADHERENCE SURFACE PREPARATION DISC GRIND	SIC	SHOT BLAST	CORROSION 5% NaCl Salt SPRAY	COEFFICIENT OF FRICTION BEFORE WEAR DRY	OILY	AFTER CABLE WEAR TEST DRY	OILY
Zinc	20	Poor	Poor	Good	Excellent	1.08	.92	.72	.63
	50	-	-		Excellent	1.08	.92	.65	.71
Nickel	50	Fair	Poor	Good	Some Pitting	1.08	.98	.82	.72
Molybdenum	20	Fair	Fair	Good	Very Light Pitting	1.07	.98	.85	.75
	50	-	-	-	Some Pitting	1.12	.87	.76	.70
None (Pure AL)		Poor	Poor	Good	Excellent	1.07	.92	.57	.57
								* .90	.66
Metco 405					Pitting	1.06	1.06	.92 .97	.87 - .92

* Tested by NSRDC

APPENDIX I

Appendix I Figures 1 Thru 20

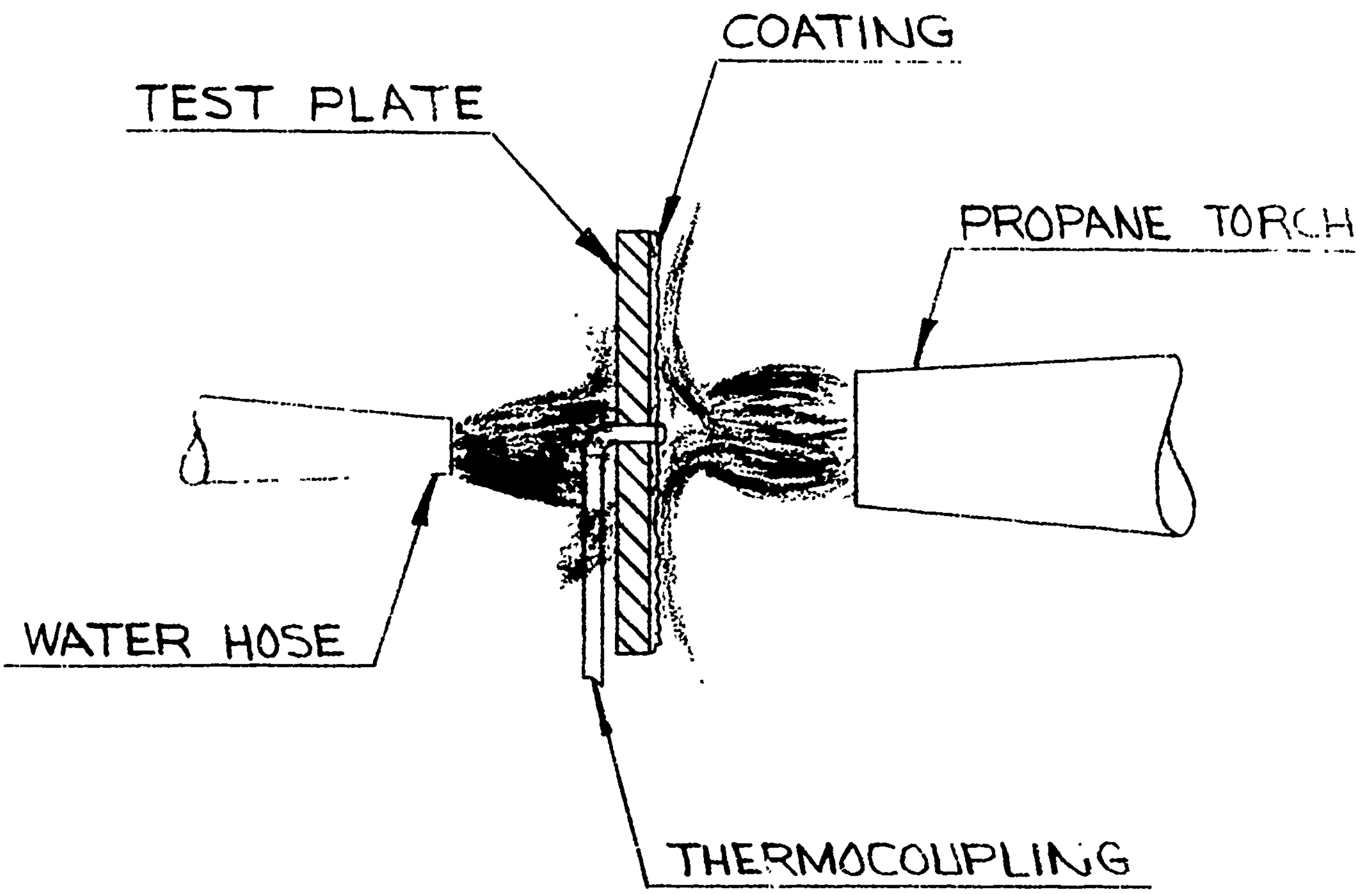

FIGURE I

BENCH TEST SET UP FOR SIMULATED JET BLAST

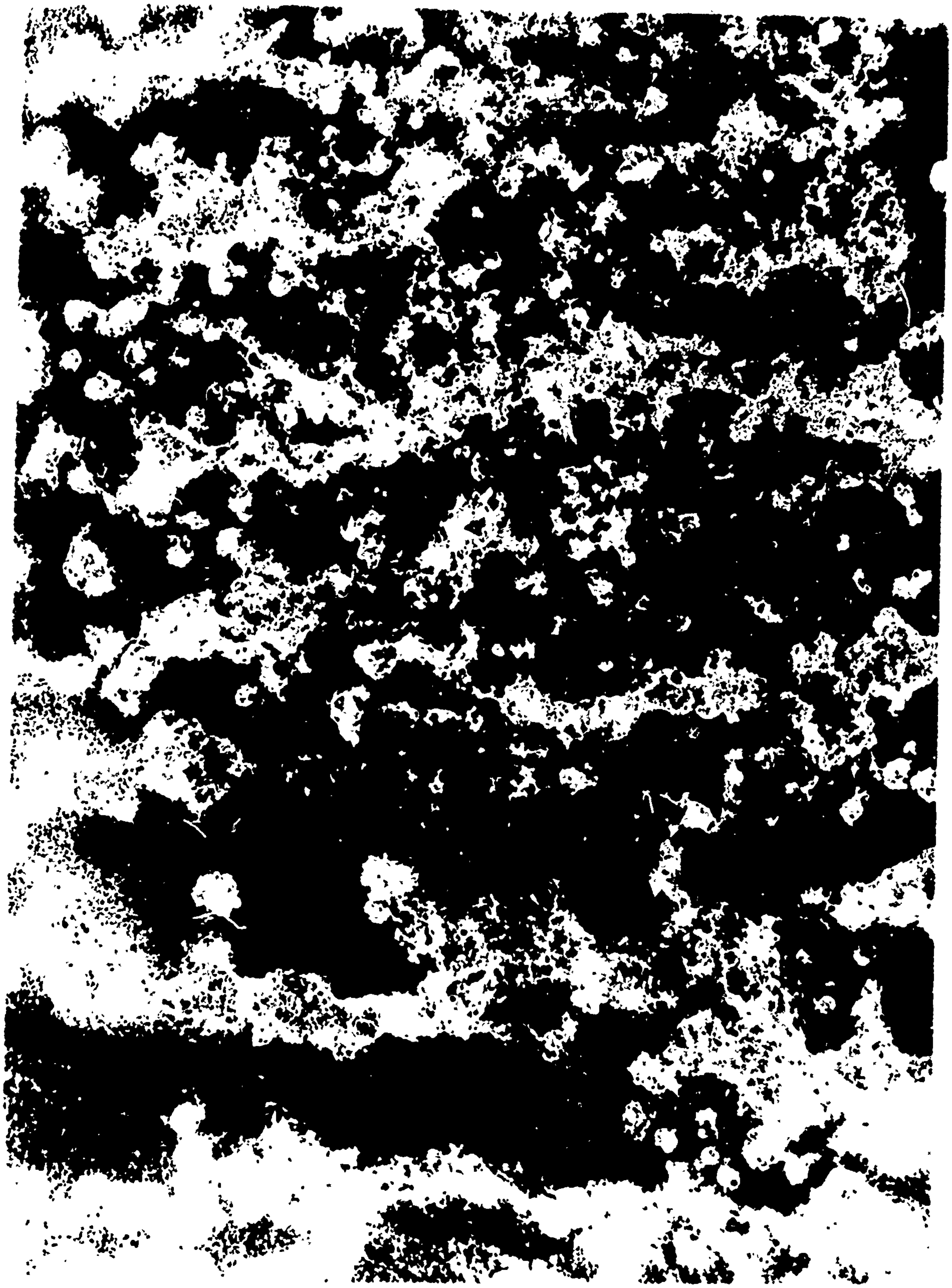

FIGURE 2

Flame Sprayed Nickel-Aluminide Coating After 168 Hours in 5% NaCl Salt Spray Test

PHOTO NO: CAN-411089(L)-10-72

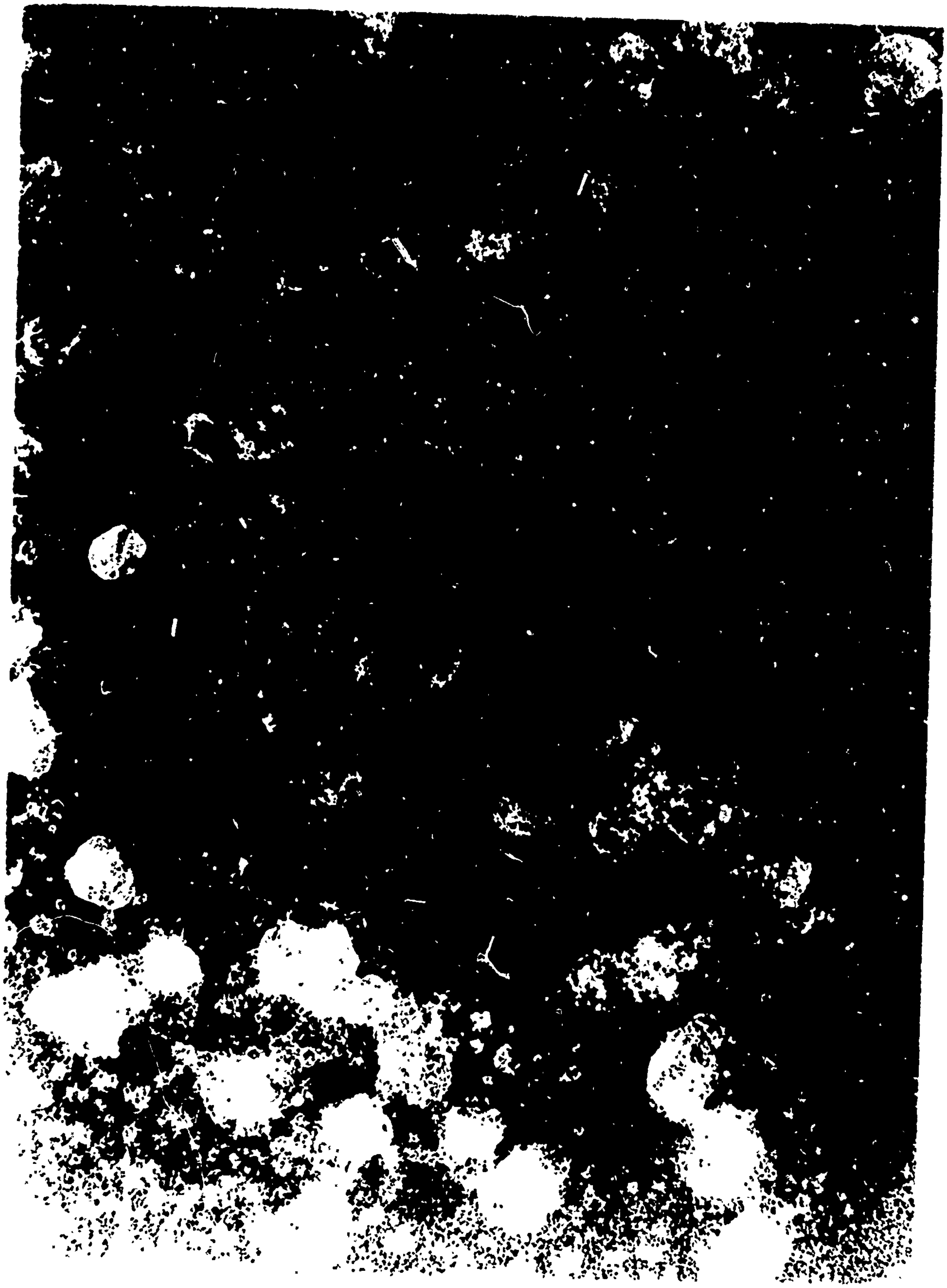

FIGURE 3

Plasma Sprayed NiCrAL Plus NiCrAL-ZrO_2 Coating After 168 Hours in 5% NaCl Salt Spray Test

PHOTO NO: CAN-411088(L)-10-72

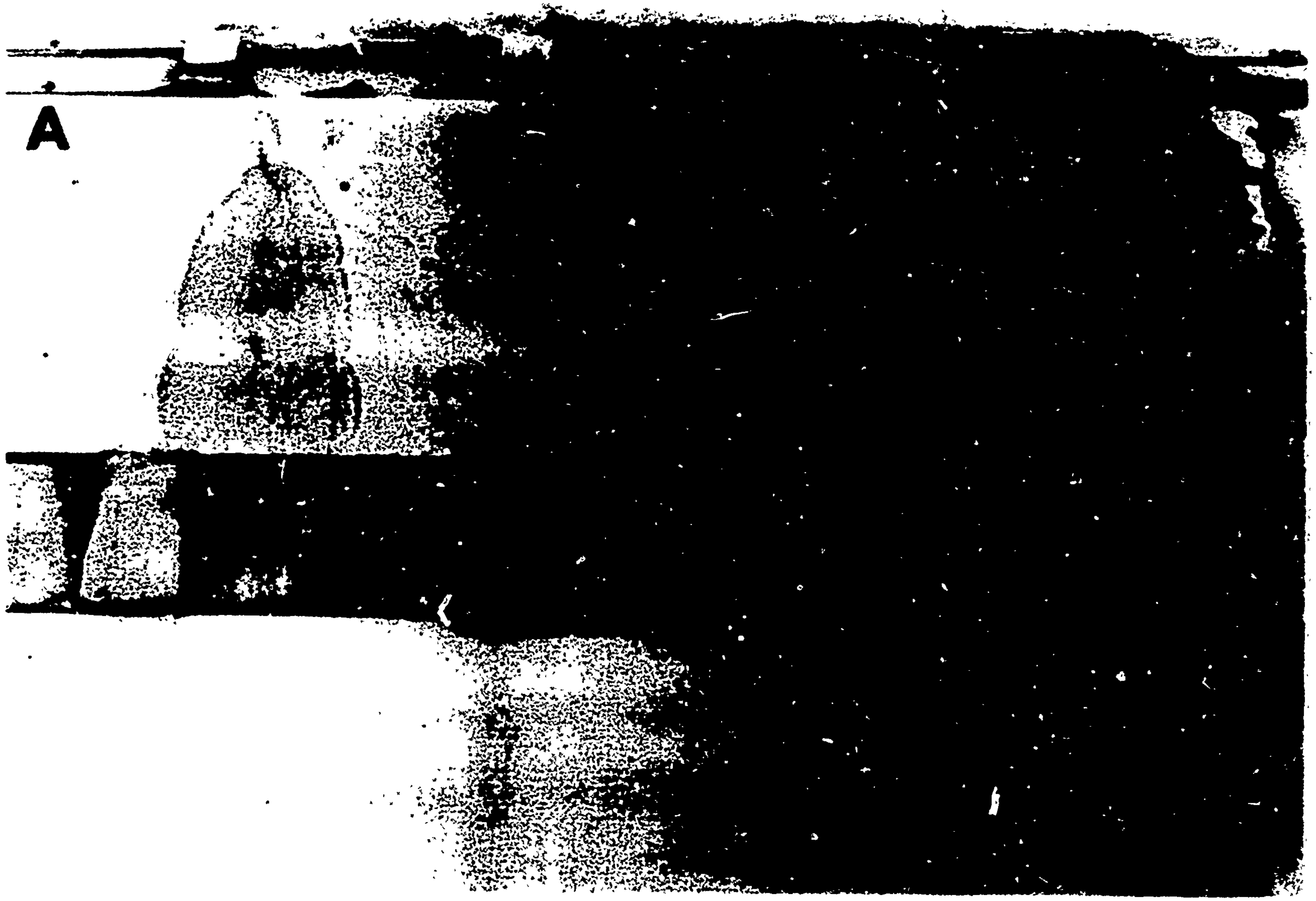

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FIGURE 4

Module Coated with Nickel-Aluminide After 20 Simulated F-14 Jet Aircraft Blasts Combined with Accelerated Corrosion

A - PALMER 113 B - METCO 405

FIGURE 5

Module Coated with Nickel-Aluminide After 70 Simulated F-14 Aircraft Jet Blasts, the Last 50 Using Salt Water Cooling for Accelerated Corrosion

A - PALMER 113 B - METCO 405

PHOTO NO: CAN-416847(L)-4-74

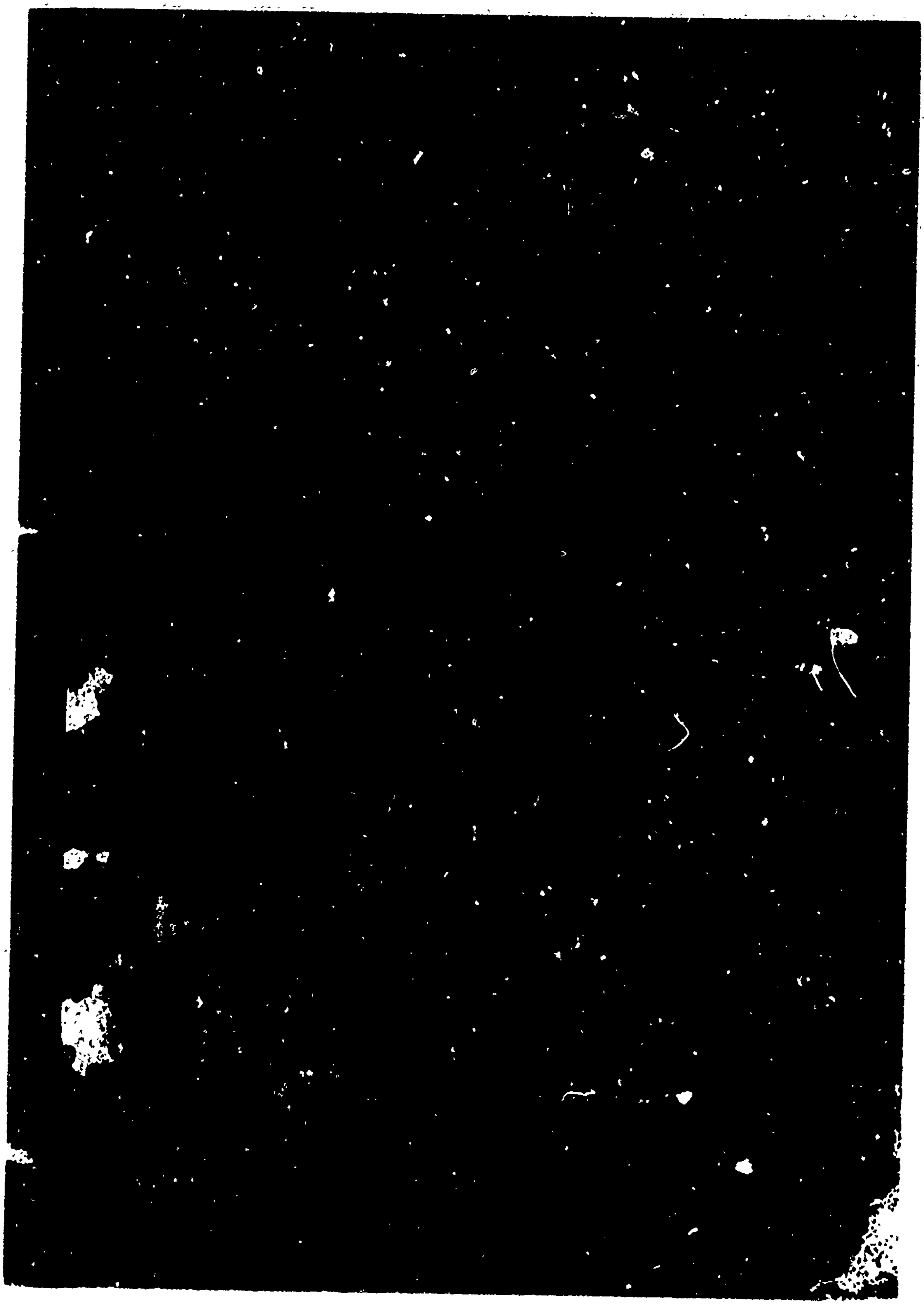

FIGURE 6

Module Coated with Plasma Sprayed NiCrAL Plus NiCrAL-ZrO_2 After 70 Simulated F-14 Jet Aircraft Blasts, the Last 50 Cooled with Salt Water for Accelerated Corrosion

PHOTO NO: CAN-416842(L)-4-74

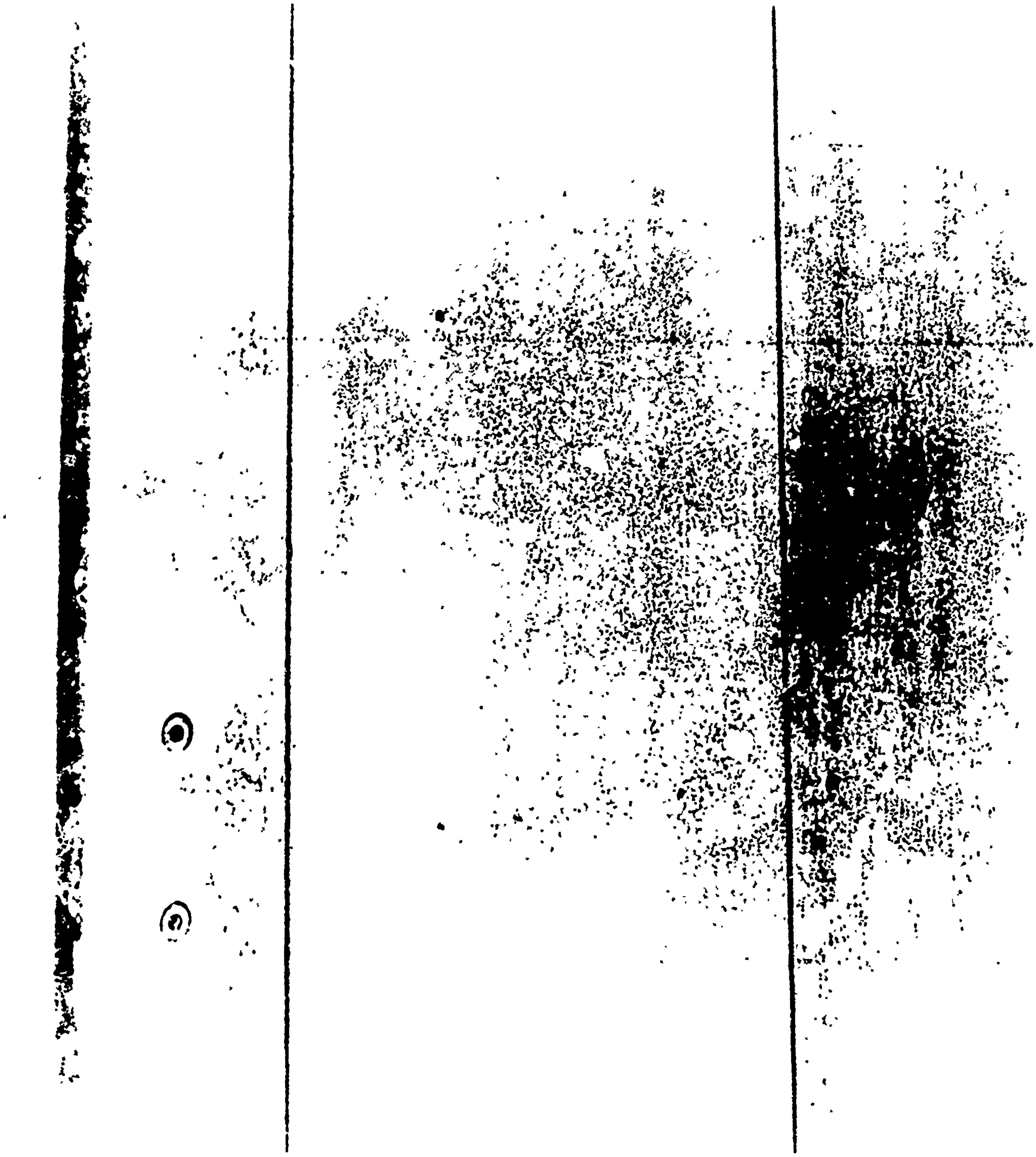

FIGURE 8

Module Coated with Flame Sprayed Nickel-Aluminide (METCO 405) After 11 Months Service on the #1 Jet Blast Deflector of the CVA-59 Surrounded by Modules with Conventional Epoxy Non-Skid

PHOTO NO: CAN-416846(L)-4-74

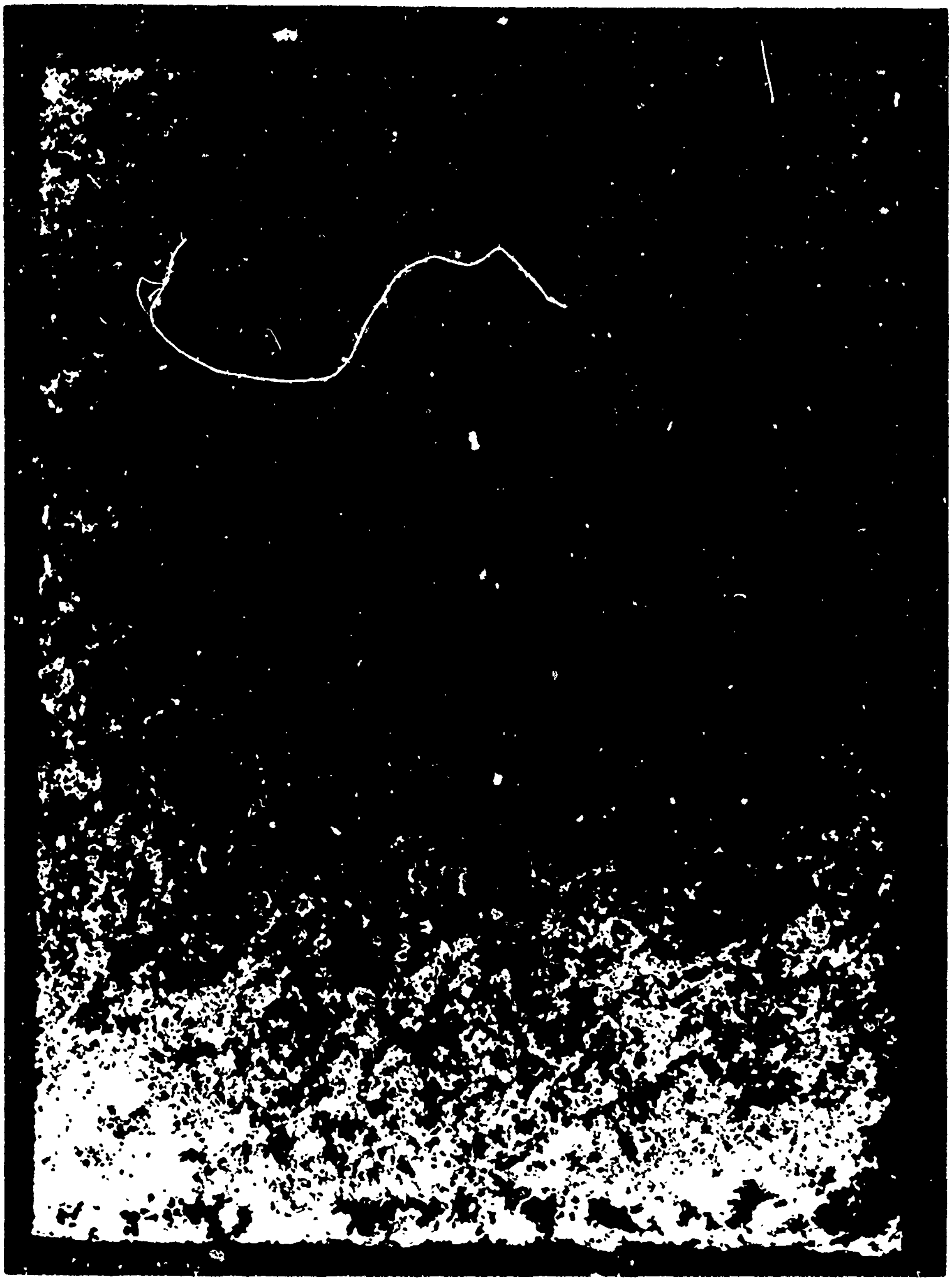

FIGURE 9

Flame Sprayed NiAL (METCO 405) Coated with Flame Sprayed Aluminum After 168 Hours in 5% NaCl Salt Spray NaCl

PHOTO NO: CAN-411084(L)-10-72

FIGURE 10

Flame Sprayed NiAL (METCO 405) Coated with Aluminum Silicone Paint After 168 Hours in 5% NaCl Salt Spray Test

PHOTO NO: CAN-411087(L)-10-72

FIGURE 11

Coating of Flame Sprayed NiAL (METCO 405) over Flame Sprayed Zinc After 168 Hours 5% NaCl Salt Spray Test

PHOTO NO: CAN-411085(L)-10-72

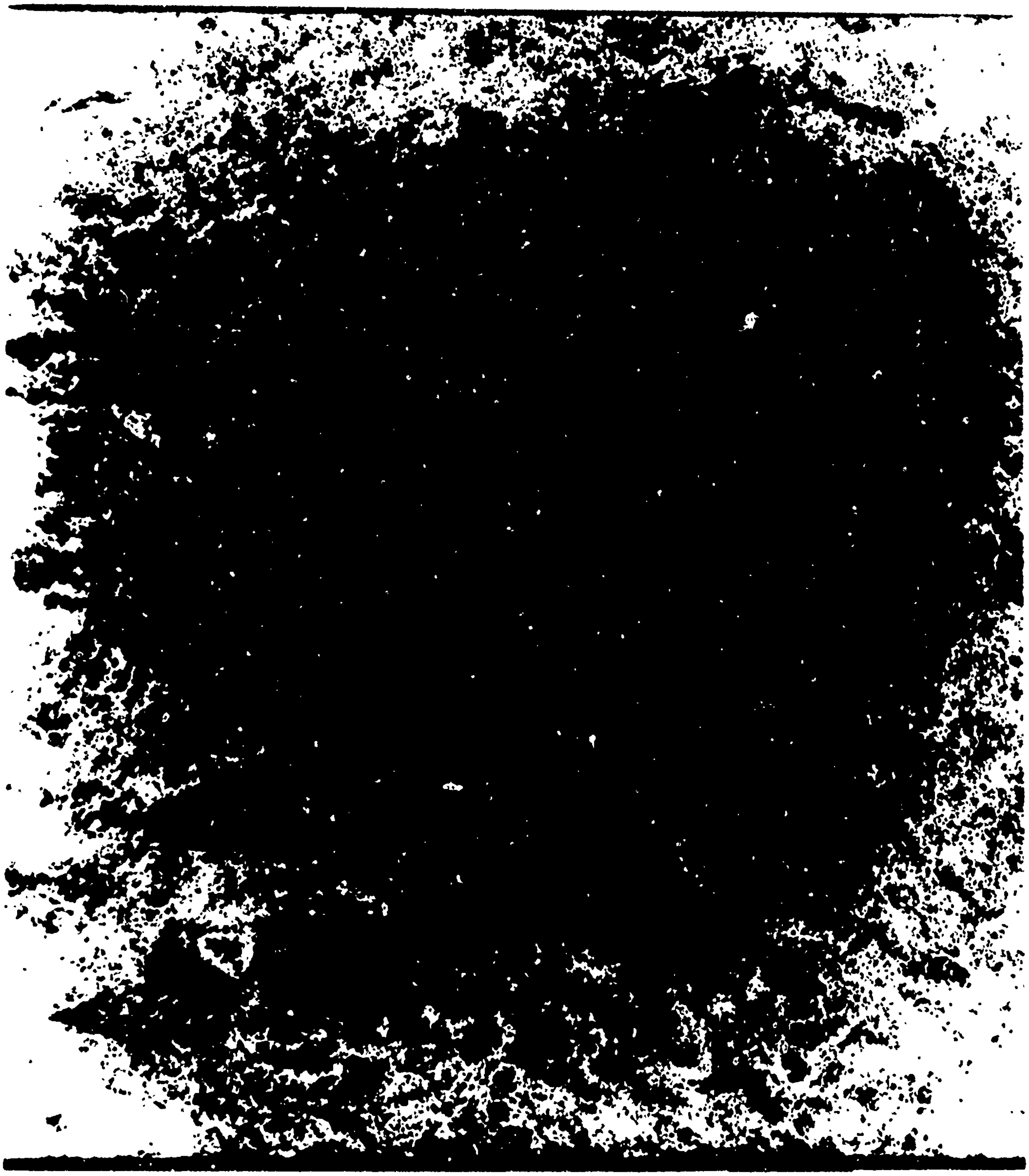

FIGURE 12

Coating of Nickel-Aluminide-Zinc - Nickel Aluminide Sandwich
After 168 Hours Salt Spray Test

PHOTO NO: CAN-411086(L)-10-72

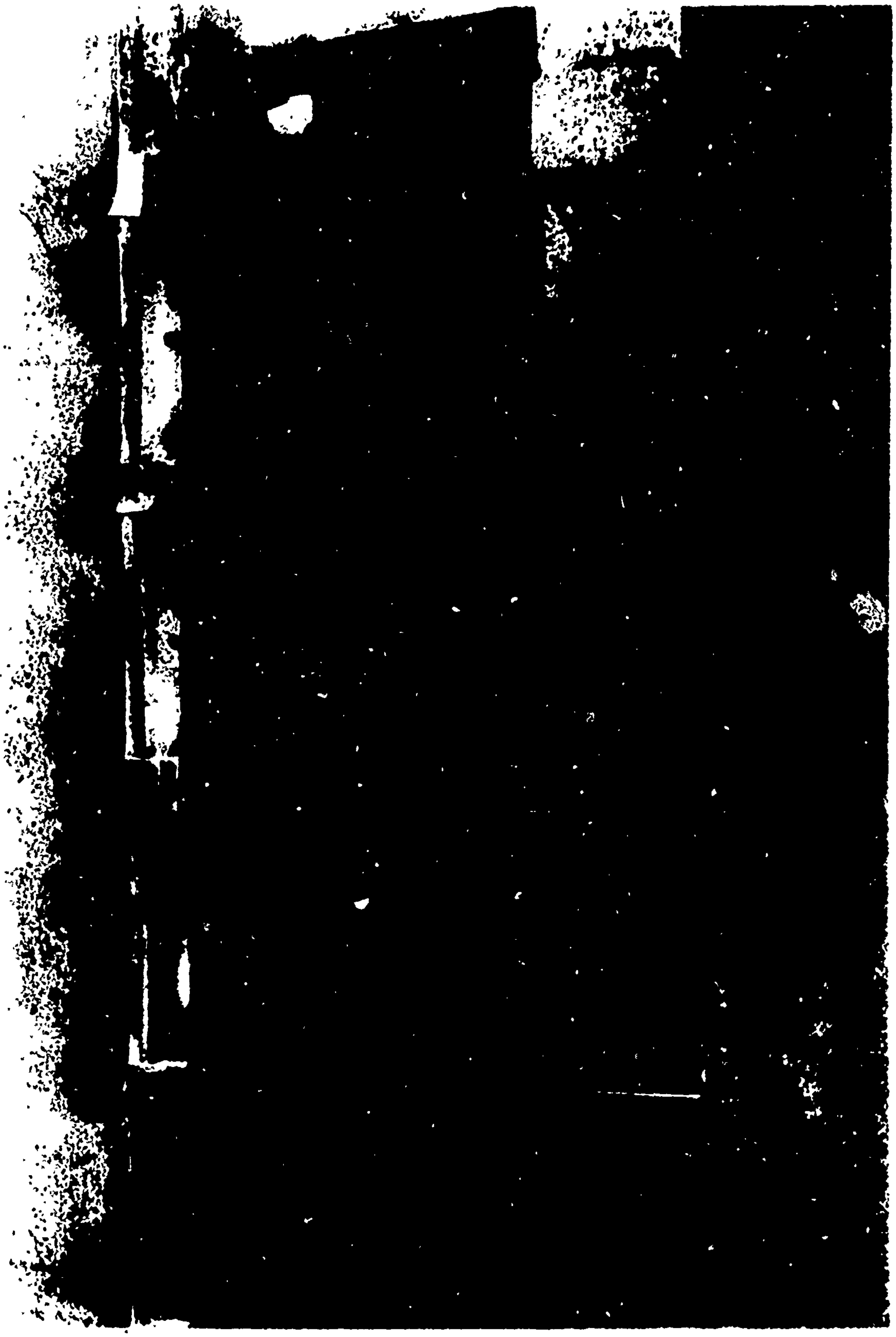

FIGURE 13

Module Coated with NiAL-Zinc-NiAL Sandwich After 70 Simulated F-14 Aircraft Jet Blasts, the Last 50 Coated with Salt Water for Accelerated Corrosion

PHOTO NO: CAN-416843(L)-4-74

FIGURE 14

Typical JBD Module Surface Coated with NiAL-Zn -NiAL (MPR-1056)
After 7 Months Service Aboard the CVA-63

PHOTO NO: CAN-416841(L)-4-74

FIGURE 15

Heavily Textured Nickel-Aluminide Coated with Aluminum Silicone Paint After Thermal Cycling Followed by 168 Hours Exposure to the 5% NaCl Salt Spray Test

PHOTO NO: CAN-416098(L)-1-74

FIGURE 16

Flame Sprayed Pre-Alloyed Nickel-Aluminide After 168 Hours in a 5% NaCl Salt Spray Test

Arrows Point to Typical Blistered Areas

PHOTO NO: CAN-416097(L)-1-74

FIGURE 17

Electric Arc Sprayed Aluminum Bronze Coating
After 168 Hours 5% NaCl Salt Spray Test

Arrows Point to Typical Blistered Areas

PHOTO NO: CAN-416099(L)-1-74

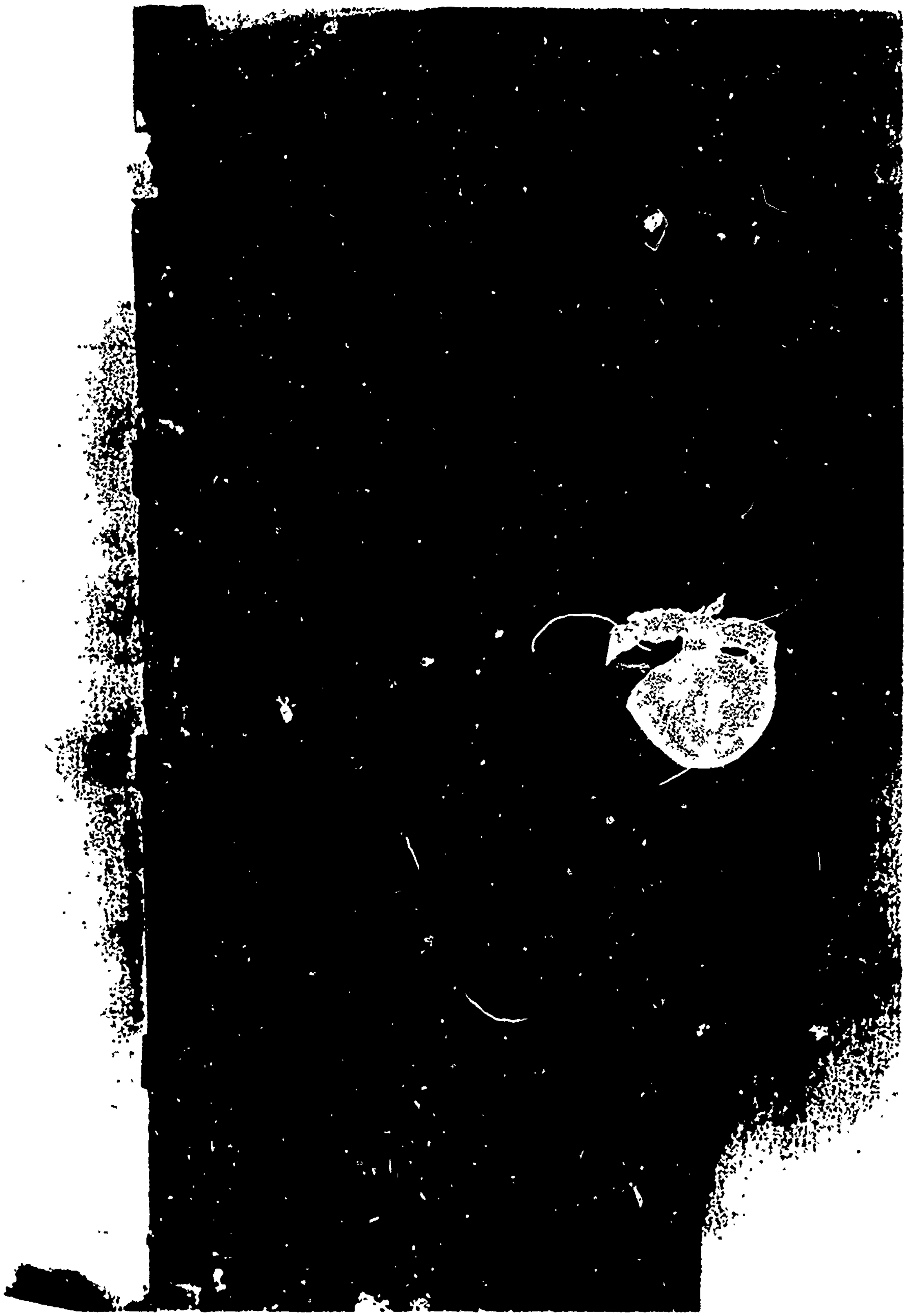

FIGURE 18

Module Coated with Electric Arc Sprayed Aluminum Bronze After 70 Simulated F-14 Aircraft Jet Blasts, the Last 50 Combined with Salt Water Cooling for Accelerated Corrosion

PHOTO NO: CAN-416844(L)-4-74

FIGURE 19

AVTEC Coating - Electric Arc Sprayed Aluminum Over Trapped Aluminum Aggregate After 70 Simulated F-14 Aircraft Jet Blasts, the Last 50 Combined with Salt Water Cooling for Accelerated Corrosion

PHOTO NO: CAN-416845(L)-4-74

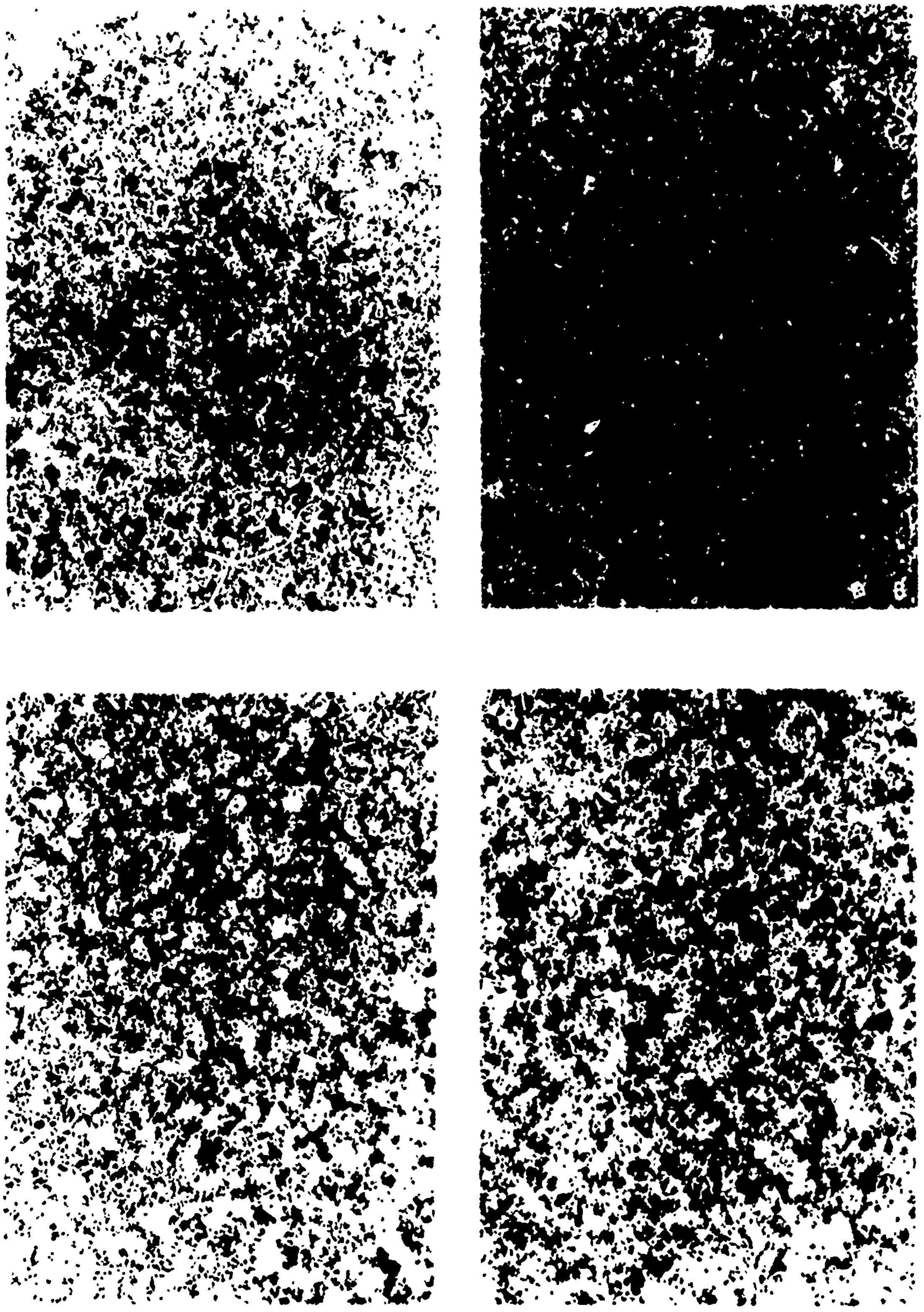

FIGURE 20

Corrosion of Electric Arc Sprayed Aluminum Plus Second Metal After 168 Hours in a 5% NaCl Salt Spray Test

A - Aluminum Plus Zinc (50%)
B - Aluminum Plus Molybdenum (50% by Volume)
C - Aluminum Plus Molybdenum (20% by Volume)
D - Aluminum Plus Nickel

PHOTO NO: CAN-416849(L)-4-74